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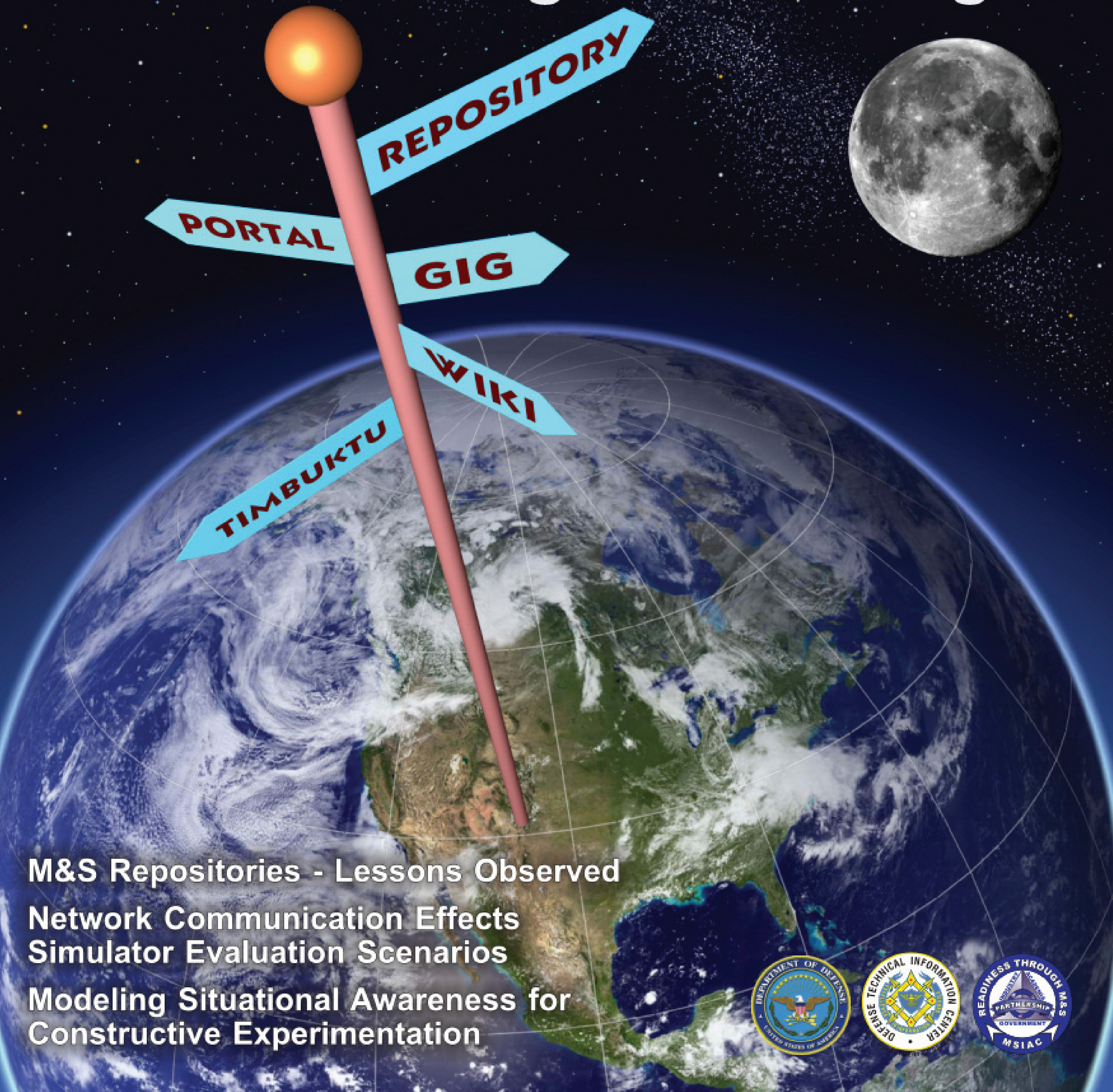
Where does good data go?



M&S Repositories - Lessons Observed

Network Communication Effects Simulator Evaluation Scenarios

Modeling Situational Awareness for Constructive Experimentation

Report Documentation Page

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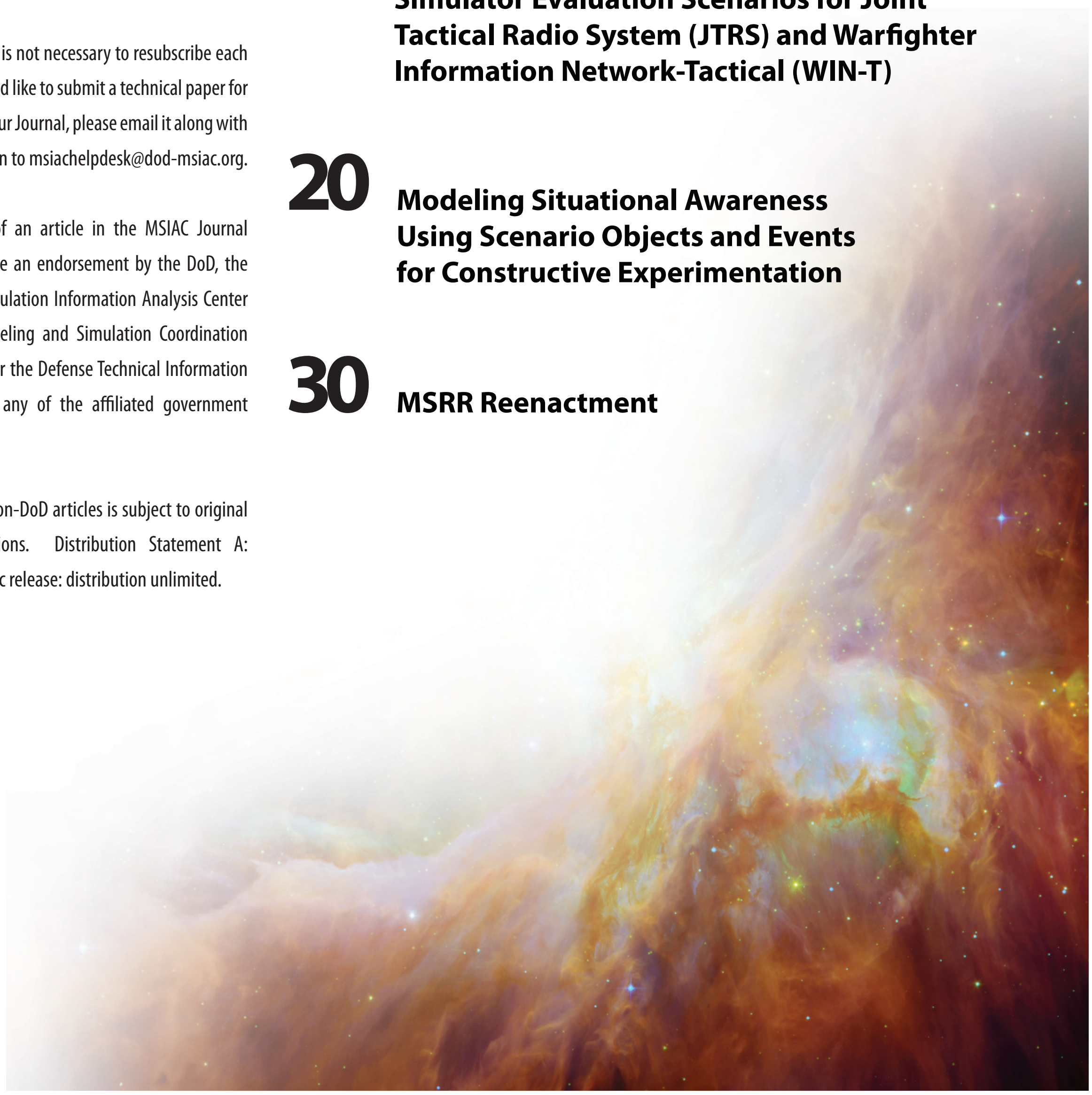

From the Director

Why should we care where good M&S data goes? And, by extension, where does good information and good knowledge go? Because if it is really good, we want to be able to use the data, information, and knowledge over and over again. As a parallel to that old saw about how to get to Carnegie Hall, we believe that how you get to simulation success is reuse, reuse, reuse. Why? Because reuse is the key to improving results, lowering risk, enhancing efficiency, and saving money on modeling and simulation. And how do we get to reuse? By storing the data is a way that promotes discovery, access, evaluation, and adaption/adoption.

The discovery, access, and evaluation of data, models, or tools are all decidedly non-trivial for current members of the DoD M&S community. But carefully designed repositories, portals, wikis, and the Global Information Grid (GIG) can help.

This issue of the MSIAC Journal presents three extremely informative articles about M&S data. The paper by Feinberg, Misch, and Talbot, "M&S Repositories - Lessons Observed", expounds on the theme of what makes the storage of M&S information effective and feasible. It also highlights new and emerging approaches to enhancing the discovery and reuse of data. The article by Colon, Tran, Yao, Anhalt, and Curiel, "Modeling Situational Awareness Using Scenario Objects and Events for Constructive Experimentation", describes how good data and information can be applied on the battlefield through improved situational awareness. The article by Leon-Barth and DeMara, "Network Communications Effects Simulator Evaluation Scenarios for Joint Tactical Radio System (JTRS) and Warfighter Information Network-Tactical (WIN-T)", is an excellent example of how data is used in M&S to represent the effectiveness of new and emerging systems.

Together, these papers examine and enlighten us on how good data should be kept, maintained, and enhanced. And this issue of the MSIAC Journal itself contributes directly to our theme: keeping good data in the spotlight. We are all fighting to avoid the worse possible destination for our good data: the metaphorical "Timbuktu" as represented by the gigantic government warehouse depicted near the end of "Raiders of the Lost Ark".

Dane Mullenix, MSIAC Director

M&S Repositories – Lessons Observed

Written by: Dr. Jerry M. Feinberg,
Gary L. Misch,
Laurie H. Talbot

ABSTRACT: *Although there is a plethora of repositories in general, and many M&S repositories in specific, their advantages to members of the M&S community are not clear. There is little hard evidence on repositories' usefulness. There is less documentation on their management. And there is almost no information on their costs.*

The Modeling and Simulation Information Analysis Center (MSIAC) has been involved in operating, managing, maintaining, and reviewing repositories since its inception in 1999. This paper summarizes some lessons observed over this time period on the usefulness of M&S repositories; what makes them successful (or not); and their ability to offer a potential cost, schedule, and risk advantage to an M&S developer or user.

The MSIAC has noted that a small, controlled repository is more likely to succeed, that a user-populated repository requires extreme discipline in the community or else political clout to succeed, and that a large and broadly-based M&S repository will underperform due to policy and business model issues. These observations, and others, are presented in an evaluation framework for a repository that includes the following fields: What is its justification? What policy supports its use? What is its scope? Who will be allowed access to it? How is it implemented, namely who populates it, who validates the information, who manages it, and who pays for it?

The paper concludes with a section discussing the future of M&S repositories. One special topic is the desirability of implementing an M&S repository with Wiki software.

Keywords:
Repositories, Cost Effectiveness, Reuse

1. Introduction

M&S practitioners have used, and continue to use, M&S repositories to store and find simulation components and data. However, the specific utility of these repositories to members of the M&S community is not clear. There is little hard evidence on repositories' usefulness, their management, or their costs.

The Modeling and Simulation Information Analysis Center (MSIAC), the Department of Defense (DoD) IAC dedicated to supporting M&S, has been involved in operating, managing, maintaining, and reviewing repositories since its inception in 1999. This paper analyzes information collected by the MSIAC on the usefulness of M&S repositories. The paper also summarizes lessons observed over this time period about what makes a repository successful. This paper also presents these observations in an evaluation framework for a repository that includes fields for repository justification, policy support, scope, access, and implementation (namely population, validation, management, and funding).

The paper also discusses the future of M&S repositories and, in particular, the desirability of implementing an M&S repository with Wiki software.

We note that this paper presents only the lessons observed by the authors. We suspect that there are also many additional lessons either not yet learned or not yet observed.

2. Background on Repositories

Quoting the current default repository of knowledge, Wikipedia [1], a repository is:

> "a place where data are stored and maintained. A repository can be ... a place where data are stored, ... a place where anything is stored for probable reuse, ... a place to store digital data."

This is distinguished from a depository, a place just for storing things (e.g., the United States Bullion Depository, also known as Fort Knox), by the desire for "probable reuse."

Repositories are desirable because they allow permitted members of a community to discover, obtain, and use/reuse resources. Properly implemented repositories can then enhance efficiency, standardization, and cost savings.

The downside of repositories often is the lack of a business model encouraging their population, use, and content sharing. For example, developers can be reluctant to share their resources; data consumers are often averse to using other's data; and owners typically want to know who will use their resources, and for what purpose, before sharing [2].

For example, if a program uses someone else's resource, the manager is taking the chance that the resource is unsuitable for the program's purposes, and hence might "be burned" by using it. Similarly, from many program

managers' views, it probably costs less to build a new resource than to ensure that someone else's resource is suitable for a particular use.

One more interesting issue with repositories is why have them at all when one can just use a modern internet search engine (e.g., Google [3]) to access almost everything that is needed. When a user employs a search engine, the user takes primary responsibility for assessing the value and suitability of the information attained. If everyone in a community uses this approach, then the assessments are repeated multiple times resulting in gross inefficiency and extra cost. The value of a repository is that the assessment is performed once and then others rely on it (to a greater or lesser degree, depending on the repository). Thus the repository's greater difficulty of individual resource discovery can be outweighed by the group savings on time and effort.

3. M&S Repository Examples

This section presents three important examples of M&S repositories.

3.1 MSRR

One well-known M&S repository is the Modeling and Simulation Resource Repository, or MSRR. The MSRR was first conceived in 1993 as the Modeling and Simulation Data Repository. As the anticipated scope of simulation interoperability increased, it became clear that defense simulations would require, and could reuse, many more resources than just databases. The models and simulations themselves became candidates for inclusion, as well as data transformation tools, VV&A histories, use histories, etc.

In a period of diminishing budgets, as perceived duplication of effort ("continually re-inventing the wheel") was escalating costs to a politically unacceptable level, a robust reuse strategy was developed to demonstrate commitment to cost effective policies. To stave off program cancellation due to lack of funds, program managers were expected to share their resources and populate the MSRR as a matter of survival.

The MSRR initially came on line in late 1995. Due to management and policy issues, the Services brought their own MSRRs on line, along with the National Ground Intelligence Center and the Missile Defense Agency.

The original concept for the MSRR was that of a true repository containing actual simulation components and datasets. However, a variety of policy factors led to providing only a catalogue of resources. Thus the current MSRR System provides retrieval of metadata descriptions only of modeling and simulation resources. Providers include the DoD system, Army, Navy, Air Force, and the Defense Intelligence Agency.

Originally, the MSRR user base was to encompass all simulation users. These ranged from the highest level planners to the lowest level tactical operators, and from major project systems engineers to individual programmers building simple models. This large scope was a significant driver in both the repository's functionality and anticipated content [4].

3.2 OAML

The Navy's Chief of Naval Operations (CNO) established the Oceanographic and Atmospheric Master Library (OAML) in 1984. OAML contains ocean models, electromagnetic (EM) models, acoustic models, meteorological models, and a category called other models. OAML also contains ocean databases, meteorological databases, acoustic databases, and electromagnetic databases. The OAML resources support the Department of the Navy, Department of Defense, research and development laboratories and Joint and NATO activities with state-of-the-art Navy-standard products.

OAML was developed to provide consistency and standardization for all oceanographic and meteorological programs used by the Navy. This was necessary since the Navy has developed and used multiple oceanographic and atmospheric models and databases. One way to guarantee consistency in simulation outputs was through policy requiring use of the resources in OAML, which is now the Navy standard library for meteorological and oceanographic databases, models, and algorithms.

The responsibility for maintaining the models and databases in OAML rests with the Naval Oceanographic Office (NAVO) located at the Stennis Space Center, Mississippi. Commander, Naval Meteorology and Oceanography Command is designated as the OAML Configuration Manager.

General descriptions of the various oceanographic and

atmospheric models and databases are provided in the "Oceanographic and Atmospheric Master Library (OAML) Summary" published by NAVO. This documentation also delineates the applications and limitations of the OAML models and databases.

OAML started in 1984 with seven databases. In 2004, it contained 35 models, 19 databases, and 8 algorithms, or a total of 62 resources [5], [6], [7], [8].

3.3 ACAT I IDEs

A valuable class of repositories is the Integrated Digital Environments (or IDEs) that have been developed for most recent ACAT I procurements (also known as Major Defense Acquisition Programs). These are small, controlled repositories with carefully selected M&S and data components with a specific purpose in support of a single program. Integrated Digital Environments are also called Integrated Data Environments or Integrated Development Environments.

From the Defense Acquisition Guidebook [9], DoD policy

> "requires the maximum use of digital operations throughout the system life cycle. … Program managers should establish a data management system within the IDE that allows every activity involved with the program to cost-effectively create, store, access, manipulate, and exchange digital data. This includes, at minimum, the data management needs of … modeling and simulation activities, …"

One excellent example of an IDE is that developed for the Joint Strike Fighter (JSF) program [10], [11].

4. Repository Evaluation Framework

The possibility of cost savings, re-use, and efficiency all indicate that repositories can be of value to the communities they serve. While it is quite easy to state that one repository has been a success, and another has been a failure, it is very hard to produce a basis for such statements.

We believe that declarations of success or failure without definitive measures are virtually useless. Consequently, this section of the paper offers a framework that supports a repository evaluation. The framework encompasses five distinct evaluation areas, or measures, each of which is described below.

The top-most measure we call "justification." This is concerned with the fundamental community need that rationalizes the establishment of the repository. This qualitative measure's values could include cost savings, re-use, efficiency, or standardization.

A second measure is "policy support." This is concerned with policies that mandate the population, use, and upkeep of the repository. Values include existence and enforceability.

A third measure is "scope." This involves the contents of the repository and specifically how much is included in it. Values include the number of resource types and the overall number of resources.

The fourth measure is "access." This is concerned with the authorized users of the repository – many or few. If the cost of replicating certain resources is high, a repository need not have a large number of users to provide value. A secondary issue is the difficulty of accessing the contents.

The fifth measure is "implementation." This measure has several dimensions. These include how the repository is populated, how the information contained in the repository is validated, how the repository is managed, and how the repository is funded.

This information is summarized below in Table 4.1.

Repository Evaluation Framework	
Measure	**Metric Values**
Justification	Cost savings, time savings, risk reduction through re-use, standardization
Policy Support	Existing, enforceable
Scope	Wide, limited
Access	Open, restricted
Implementation: Population, Validation, Management, Funding	Single person, resource owners, programs, …

Table 4.1 – Basic Framework

5. Evaluation of Selected M&S Repositories Using the Framework

We can test the framework proposed above by using it to evaluate the three example M&S repositories.

We stress here that these evaluations are the opinions of the authors only.

5.1 MSRR

Table 5.1 contains our evaluation of the MSRR in terms of the repository evaluation framework.

Repository Evaluation for MSRR	
Measure	**Metric Values**
Justification	Cost savings, time savings, risk reduction through re-use
Policy Support	Inconsistent – currently weak to non-existents
Scope	Large (virtually unrestricted)
Access	Theoretically wide but practically hindered by implementation factors
Implementation: Population, Validation, Management, Funding	Population – originally performed by resource owners (was ineffective) and currently performed by MSIAC. Validation – performed by resource users. Management – MSIAC but without any clear direction. Funding – no recent funding for maintenance or update.

Table 5.1 – Evaluation for the MSRR

5.2 OAML

Table 5.2 contains our evaluation of the OAML in terms of the repository evaluation framework.

Repository Evaluation for OAML	
Measure	**Metric Values**
Justification	Standardization, cost savings, time savings, risk reduction through re-use
Policy Support	Clear and enforceable
Scope	Service-wide, limited to specific topics
Access	Limited to designated users
Implementation: Population, Validation, Management, Funding	Population, validation, management, funding – Navy and the Program Office

Table 5.2 – Evaluation for OAML

5.3 ACAT I IDE

Table 5.3 contains our evaluation of an ACAT I IDE in terms of the repository evaluation framework.

Repository Evaluation for an ACAT I IDE	
Measure	**Metric Values**
Justification	Cost savings, time savings, risk reduction through re-use, standardization
Policy Support	Clear and enforceable
Scope	Program-wide, limited to specific topics
Access	Limited to designated users
Implementation: Population, Validation, Management, Funding	Population, validation, management, funding – the ACAT I program

Table 5.3 – Evaluation for an ACAT I IDE

6. Lessons Observed and Issues for M&S Repositories

This section summarizes some lessons observed by the authors over the course of their involvements with M&S repositories. We find it easiest to categorize these lessons using the framework for repository evaluation.

6.1 Lessons observed – Justification

Apparently, it has been quite easy to justify the development of M&S repositories. One standard method is the "if you build it, he will come" [12] approach. This has not proven true for the MSRR, as the system seems to be very under-utilized. The wide-scope MSRR can be justified on several grounds, primarily reuse, but the issues of return on investment or cost savings are shakier due to the low utilization.

In other cases, this justification has proven out. A shining example is OAML where the desire for standardization across the Navy M&S community largely has been attained. Standardization and control leading to reuse also has justified the ACAT I IDEs.

6.2 Lessons Observed – Policy Support

It is quite clear that a strong policy mandating both the use and the population of a repository is a main key to success.

Such a policy is easier to develop and implement if the scope of the repository is not too large since the number of affected users is more limited and they are then easier to control.

The MSRR could have been much more effective if there had been strong accompanying policy requiring developers to supply the metadata for their resources, however the span of management authority within the DoD makes implementation of such strong policy problematic. This holds true for all of the nodes of the MSRR.

6.3 Lessons Observed – Scope

Our review indicates that the wider the scope of the repository, the more difficult it is to make it a success. Part of the reason, discussed above, is because it is harder to implement supporting policy. Another part is that it is harder to maintain control over a larger number of resources and another part is the cost – the greater the number of resources, the more the cost to populate and update the repository. Finally, attempting to serve many different types of users increases the repository requirements, consequently complicating the design and subsequent implementation, leading to higher costs.

6.4 Lessons Observed – Access

We have not seen a strong correlation between the success of a repository and the scope of allowable users. What seems to be much more important is the ease of access to the repository. OAML users require special approval, but seem to obtain this easily. ACAT I IDE users are quickly authorized by their programs. In both cases, repository effectiveness is probably improved by having remote access available with associated security procedures in place.

The reported ease of use of the MSRR varies. Many potential users are confused by the fairly archaic interface. Yet many experienced engineers have no problems with the system.

Finally, the policy/design underlying the MSRR has permitted metadata only to be stored. Consequently, discovering the resource in the MSRR is not equivalent to attaining the resource. Without an effective business model encouraging sharing, a metadata repository will not succeed.

6.5 Lessons Observed – Implementation

For populating resources into the repository, the method utilized by the MSRR is totally ineffective. This method relies on the resource owner's "good will" to take the steps required to insert the resource. This has failed on several counts. The first is the time and effort (hence cost) involved. The second is that publication of a resource's existence with a point of contact leads to frequent communications that can require significant time and effort on the contact's part. The third is a potential loss of control of the model's code since the MSRR relies on the resource owner for configuration management but changes to the code could be made by any third party user. A fourth is a perception by several owners that only they know how to execute their particular simulations properly as it is thought to be more of an "art" than a "science" to run them.

OAML and the ACAT I IDEs effectively pay for the population of their repositories. There is also strong policy (by the Navy or by the program office) requiring use of their repositories. This has been effective.

Validation and configuration management of MSRR resources is performed by the resource owners. Validation of OAML models is performed by the OAML program. Validation of ACAT I IDE models is performed (at least in theory) by the program office. We have not observed any problems with these methods.

Management of OAML and of an ACAT I IDE is straightforward and executed by the program offices. Management of the MSRR has been inconsistent, fractured, and at times chaotic. This inconsistent management of the MSRR has led to reduced usage and has also precluded the development of effective policies.

Funding of repositories is always an issue. The management of a repository has to justify the program to maintain its budget. Expanding the scope of a repository demands a higher budget. OAML and an ACAT I IDE live within their fluctuating budgets by constraining the number of resources and some of the associated services provided. In fact, there are many examples of building very effective repositories on a tight budget by choosing to constrain the number of resources being managed.

6.6 Summary of Lessons Observed

So, in summary, it first appears that a small, controlled repository is more likely to succeed.

Second, a user-populated repository requires extreme discipline in the community or else political clout to succeed. Third, a large and broadly-based repository may underperform due to policy and business model issues. Fourth, while incorporating a broad user base may appear to be wise, constraining the user base from which initial requirements are derived can lead to a more affordable system without necessarily impacting scalability.

7. Future for M&S Repositories

How should repositories for models and simulations change to be more effective, efficient, and affordable? In our view, the answer to this question centers on the major evaluation criteria in our framework.

7.1 Suggestions

Justification: there is a continuing need for access to modeling and simulation components for adaption or adoption, and to support standardization. Repositories are here to stay provided that their contents are properly validated and reusable so as to compete cost effectively with internet search engines. The initial step always is to determine who the users of a repository are going to be and what these users are going to want (requirements).

Policy support: future repositories will succeed when supported by strong policies in two areas. The first is to mandate the use of modeling and simulation components that are contained in the repository, whether for adoption, or adaption, or supporting new development. The second is to require the population of these repositories with a set of M&S components satisfying important selection criteria. These policies need to be enforceable.

Scope: future repositories have a greater likelihood of success if they are narrower in scope and controlled. Thus we suggest a set of separate, constrained, limited-scope repositories that are tightly controlled, but linked so that discovery across the entire set is possible.

Access: future repository or repositories should allow wide access provided this does not drive the architecture/design to a difficult-to-maintain, costly-to-implement solution. The design requirements should be derived from a smaller, cohesive set of users. Certain resources can always be protected passwords or other means if necessary.

Implementation: future repository population should be controlled by the repository manager/owner who is also responsible for validating the information contained therein. These individual manager/owners should also pay for development, population, and upkeep. It does not matter if the repository is distributed across various nodes provided that it is presented to the user as one logical repository.

7.2 Other Approaches

As discussed earlier, relying on internet search engines presents a viable possibility for replacing repositories, but these engines introduce difficulties of their own. A more interesting approach is developing a Wiki-based repository [13] in which users or third parties populate the repository with information about resources. This approach eliminates the bottleneck of relying upon a specified entity or group to perform all the work of population and "spreads the costs around." However, it can lead to free-for-all battles on the information content with competing views of a resource playing out in public.

Internally, the MSIAC has been testing a Wiki-based repository for some of its own resources. In this case, the "editors" of the resources are a limited group and the scope of the repository is controlled. We hope to report more details of this approach in a later paper.

Finally, amongst all of the hoopla and teeth gnashing concerning repositories, we suggest heeding the words of a famous British knight:

> "…you can't always get what your want,
> but if you try sometimes, you just might
> find, you get what you need" [14]

8. Acronyms

ACAT I	Acquisition Category I - Major Defense Acquisition Programs
CNO	The Chief of Naval Operations
DoD	Department of Defense
EM	Electromagnetic
GIG	Global Information Grid
IAC	Information Analysis Center
IDE	Integrated Data Environment
JSF	Joint Strike Fighter
M&S	Modeling and Simulation
MSIAC	Modeling and Simulation Information Analysis Center
MSRR	Modeling and Simulation Resource Repository
NAVO	Naval Oceanographic Office
OAML	Oceanographic and Atmospheric Master Library
SPM	Smart Product Model
VV&A	Verification, Validation, and Accreditation

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Biographies

Jerry Feinberg, of Alion Science and Technology, is the Chief Scientist at the Modeling and Simulation Information Analysis Center (MSIAC) in Alexandria, VA. He has supported information analysis and repository initiatives for DoD and for the Navy. Most recently, he led a MSIAC survey of repositories to determine how they have provided value to their users.

Gary Misch, of Alion Science and Technology, is the Knowledge Manager and Director of Technology at the MSIAC, Alexandria, VA. He was the project manager for the Defense Modeling and Simulation Resource Repository, and developed the original requirement for the Navy Battle Force Tactical Training System.

Laurie Talbot, of Alion Science and Technology, is a Senior Military Operations Analyst and MSIAC help desk contributor, supporting the Military Modeling and Simulation Community in the Florida Simulation Center, Orlando Florida. He was previously assigned for three years as the Air Force M&S Subject Matter Expert for the Air Force MSRR.

Network Communication Effects Simulator Evaluation Scenarios for Joint Tactical Radio System (JTRS) and Warfighter Information Network-Tactical (WIN-T)

Written by: Carlos Leon-Barth,
Ronald F. DeMara

ABSTRACT: *Various simulators have been identified as Communications Effects Servers (CES) to predict the bandwidth necessary to support Future Combat Systems (FCS) training exercises. This paper examines features of CES's within particular Future Combat Systems communication simulation scenarios that are defined to serve as benchmarks. The scenarios are designed to evaluate the demands of FCS as part of the Objective Force (OF), providing results that can be measured and used to correlate results between different CES technologies and verify their accuracy.*

At present, the Caspian Sea is the accepted test terrain database for FCS/OF communications [1]. The outcome generated by such scenarios can produce reliable information that can be used to compare the fidelity of the FCS communications for a defined environment. Moreover, the results provided from each of these models can be used to evaluate communications capacity requirements of small FCS exercises including other elements such as embedded training that is suspected to increase the existing FCS communications demands during certain stages of the simulation.

Overview of FCS Network

Currently Future Combat Systems (FCS) contractors propose an alternative FCS protocol that will integrate JTRS and WIN-T into FCS. The protocol System-of-Systems Common Operating Environment (SOSCOE) which is under development has the goal of enabling straightforward integration of separate software packages, independent of their location, connectivity mechanism and the technology used to develop them [2]. FCS will employ an integrated computer system to host SOSCOE, support networking, and employ consistent data storage/retrieval across all FCS cells and applications. Nevertheless, SOSCOE is not included as part of any of the CES simulators currently available.

FCS is intended to provide the core block of the US Army's Future Force. The FCS Family-of-Systems (FoS) is to be coupled to the C4ISR network by a multilayered Communications and Computers (CC) network with extraordinary range, capacity and dependability. The CC network provides secure, reliable access to information sources over extended distances and complex terrain.

The CC network is primarily embedded within the mobile cells and moves with the other combat vehicles in formation and can be replaced adhoc in case of annihilation, strengthening the capability of the command, control, communications, computers, intelligence, surveillance, and reconnaissance (C4ISR) [3] network on the move. The FCS CC communication network consists of several existing communication systems such as Joint Tactical Radio System (JTRS) Clusters 1 [4] and 5 [5] with Wideband Network Waveform (WNW) and Soldier Radio Waveform (SRW), Network Data Link and Warfighter Information Network–Tactical (WIN-T). Most of these systems emerged from earlier technologies and are not designed to accommodate future FCS bandwidth requirements. Every FCS vehicle in the Unit of Action (UA) should be equipped with a *4- or 8-channel JTRS Cluster 1*. Each channel has constrained bandwidth capabilities. Soldiers and other weight and power-constrained cells should be equipped with a *1- or 2-channel JTRS Cluster 5*. In addition to the WNW and SRW communications backbone, the software programmable JTRS will support other waveforms to ensure current force Joint, Interagency and Multinational (JIM) interoperability. The WIN-T will provide additional communications capability within the UA, as well as reach to communication layers above — intra- and inter-UA, and UA to Unit of Employment (UE) —and range extension.

Multiple vehicles and communication links support the operation and deployment of FCS vehicles. Figure 1 depicts the support vehicles and network communications required to conduct a multi-national force. Since each mission is different, the characteristics of the mission will dictate the vehicles and communications involved. Nevertheless, most missions will require an Unmanned Air Vehicle (UAV) to provide real-time surveillance information regarding the terrain, battle conditions and enemy location. The Central Air Data Computer (CADC) will relay communications to satellites that pass on information to the C4I grid.

FCS Scenarios and Embedded Training (ET) for CES Stimulation

Embedded Training (ET) capability will be developed as an integral part of the FCS manned cell and C4ISR architectures [6]. Specifically, while the vehicles are transported, training exercises are executed as simulations that mimic the actual engagement scenario.

Therefore, ET generates additional traffic that the CES simulators should accommodate for realistic CES bandwidth tests results. Knowing how much bandwidth the current technology can accommodate is an important metric reflected in future designs.

A typical FCS scenario is depicted in figure 1. It evolves different radios and systems that control the communication on the move and re-establish connectivity in case of attack. Hence, the FCS communication network to be evaluated for ET consists of a group of systems such as JTRS Clusters 1 and 5 with WNW, as well as SRW, Network Data Link and WIN-T.

The communications between vehicles of the UA is handled by the *JTRS Cluster 1*. Dismounted solders or weight sensitive vehicles are equipped with a *1- or 2-channel JTRS Cluster 5*. Due to secrecy, the transmission and wave characteristics of JTRS radios are not available for publication, but are essential to realistically model the wave and transmission patters that interact with any terrain database and weather characteristics of a simulation. Typical values are provided by some CES simulators but not released for publication due to contractual restrictions.

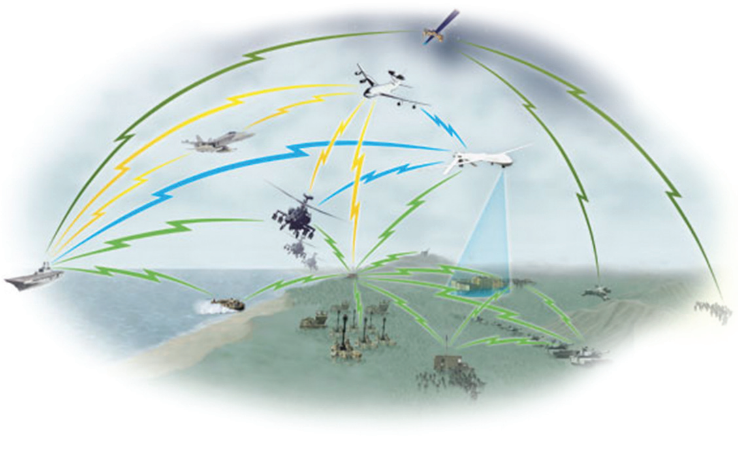


Figure 1: Depiction of FCS Scenario [7]

FCS Communication Effects Simulators

Three different emerging CES were studied, COMPOSER, QUALNET and Omnet++. The COMPOSER provides models that through a composition tool can be placed in a certain location and interact with United States Geological Survey (USGS) terrain data. However, the radio models are being developed and allow modifications. Its network hierarchy is proprietary and allows no modification. Qualnet is a commercial tool made by Scalable Network Technologies (SNT). This simulator includes FCS radio models as part of its FCS package. JTRS and WIN-T models are available under unique license agreements. Qualnet can interact with terrain databases and provide FCS models. Omnet++ is an open source communications simulator that can be 100% customized [8]. Interaction with 3D data is limited, but can be improved through further development. All three CES provide a 3-dimensional visual image of the undergoing communications and the ability to preset cells at a certain Global Positioning System (GPS) location for analysis. However, modifications to the communications network initial layout are an evolving capability. In contrast, open source OMNET++ provides source code that can be modified and manually customized [9]. Network models are based on pre-configured models, but each model can be copied and customized to model different protocols and designs. Different examples model wireless and LAN networks that can be adapted to any given model specifications. Existing models can represent Mobile Internet, Mobile Data Link and 802.11 among others.

SNT-Qualnet takes a different approach providing a unique simulator that structures the FCS network using a layered approach based on the Open Systems Interconnection Basic Reference Model (OSI) [10]. The FCS network architecture represented in SNT is a hierarchically structured network. The architecture consists of the FCS proprietary Mobile Intranet (MI) Layer and the Mobile Data Link (MDL) Layer. The MI Layer is mainly responsible for the routing support while the MDL layer provides medium access to the wireless channel [11].

The MI Layer includes the following models:

- Region formation
- Region Access Point (RAP) selection
- Subnet formation
- Gateway selection
- Intra-Region routing using Hazy Sighted Link State Routing Protocol (HSLS)
- Inter-Region routing using Multi-level Abstracted Link State Routing (MALSR)
- Radio Open Shortest Path First (ROSPF)
- Multi-Point Relay (MPR)

The MDL Layer includes the following model of Unified Slot Assignment Protocol (USAP). At the lowest level of the hierarchy are *Cells* (or nodes).

As illustrated in Figure 2, all nodes in the network are cells. The Cells dynamically form (and re-form) individual *Regions* using a Region formation algorithm.

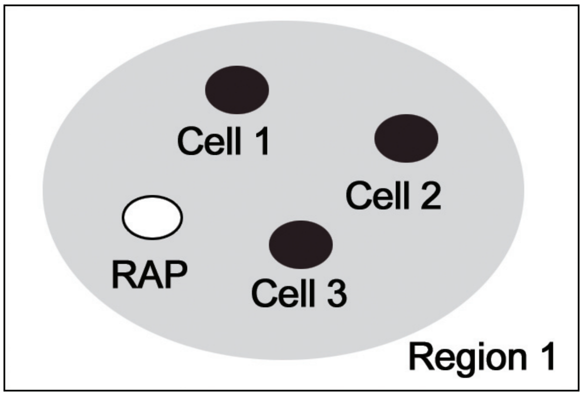


Figure 2: Cells and Regions

Subnets are predetermined. A Subnet can have more than one Gateway and a Gateway can belong to more than one Subnet. In fact, routing within a Region is accomplished using HSLS. To route between Regions, MALSR is employed and is executed on the RAPs.

Finally, routing between Subnets is achieved using ROSPF on the Gateways. Medium Access Control (MAC) within Subnets is achieved using USAP. Thus, transmissions within and between Regions of a Subnet rely on USAP. However, transmissions between Gateways may use any medium access protocols, such as Carrier Sense Multiple Access (CSMA), Time Division Multiple Access (TDMA), or even USAP. The choice of which MAC protocol to use between Gateways depends on the radio equipment the Gateways are equipped with. Figure 3 depicts HSLS and MALSR and how ROSPF connects gateways.

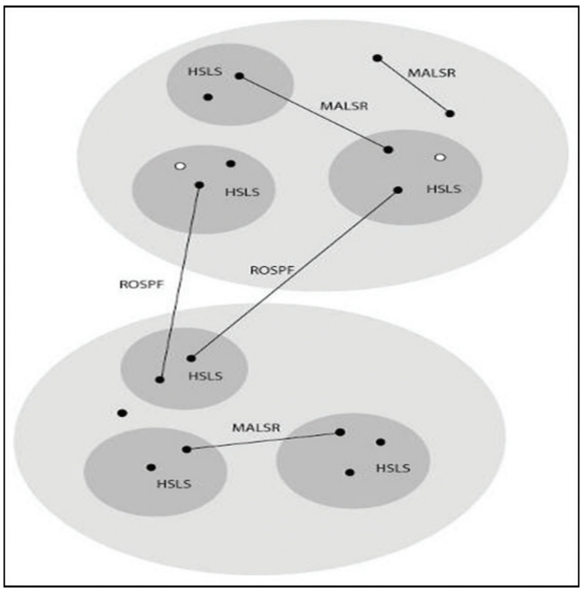


Figure 3: HSLS, MALSR, ROSPF

For FCS environments such as those depicted in Figure 1, SNT provides a basis that was adapted to FCS network traffic according to current FCS specifications. This includes support for JTRS radio cluster 5 with two channels, thus limiting our experiments to scenarios based on land operation and inter-vehicle communication such as the example quoted earlier regarding the deployment of an objective force to a location near the Caspian Sea.

Omnet++ and COMPOSER CES simulators studied do not provide a layered approach or a path to configure each cell internally. Most cells could be configured as a network node, but the communications modeling fidelity of that approach may not be sufficient. Other issues such as mobile communications may not be correctly modeled. The JTRS radios models were not available for use in this study; nonetheless all CES studied proved useful to identify issues on Line-of-Sight (LOS) communications on variable altitude terrain.

Location of Scenario Selected for CES Evaluation.

The Caspian Sea is the standard location used for FCS communications testing located between latitude 48° N and 36° N and longitude 47° E, and 54° E, covering more than 293 thousand square miles.

Given the immensity of the area we will concentrate on a small scenario based out of the Atyarau airport located at 47° 07′ 27.90″ N and 51° 49′ 29.92″ E. Figure 4 depicts the location courtesy of Google Maps.

Figure 4: Atyarau Airport

The Atyarau Airport was selected due to its proximity to the North shore of the Caspian Sea. However, any location in the world will work for the test.

The Caspian Sea particularly suits the FCS scenario mentioned earlier regarding vehicles deployed for combat. The airport has buildings and access roads easy to map using Global Positioning System (GPS) coordinates. Moreover, the terrain elevation is easy for any vehicle to traverse and is included in the Caspian Sea USGS database.

The possibilities to find Digital Elevation Model (DEM) and Digital Terrain Elevation Data (DTED) terrain databases are high due to its proximity to the Caspian Sea, but were not verified. GPS coordinates can be used to position each communication cell and use a waypoint feature to move each vehicle (cell) across the terrain as desired, as their interaction with weather and terrain is observed. The suggested location for the scenario is irrelevant for the results of the experiment. Any location in the globe will be sufficient for research. Therefore, any available DEM or DTED data can be used to establish waypoints for the experiment.

Network Components Selected for Simulation

In [12], MITRE suggests that the initial hardware to be used is mostly COTS while JTRS radios connect the subnets and nets together. Therefore we will concentrate on the use of JTRS radios for the inter-cell communication. Mobile Ad Hoc Network (MANET) routing software that runs on Linux provides IEEE 802.11 connectivity for which wireless protocols are also included as part of the subnet communication. SNT FCS version provides JTRS radio models based on their abstract model configured to JTRS specifications, while nets and subnets are routed using FCS proprietary Mobile Intranet Protocols (MI) which define the Hierarchy formation protocols and the routing protocols. RAP protocols define the regions while the subnets are defined by HSLS. The ROSPF protocol and the Multi Relay Protocol control the routing. The Mobile Data Link Layer uses USAP (Boeing-FCS-USAP). The physical layer is already defined for FCS based on predefined FCS physical layer characteristics based on the antenna's radiation patterns, frequency, bandwidth and gain. Protocol detail is not provided as it is beyond the scope of this paper. However, it is essential to understand the details of FCS communication to interconnect available models.

Our proposed baseline can be used on any FCS capable CES. We have selected a straightforward scenario that can produce measurable results that verify CES operation. The use of JTRS radios is essential since they carry the communication between cells. Other models such as MANET, MI and RAP provide low level wireless communication, but may not be available on all simulators. Available COTS models such as IEEE 802.11 can also be used to simulate wireless networks. The idea is test the interaction of the available models on the CES with the terrain from the database. Since FCS communications is loose and not yet defined and constantly evolving, models provided from each simulator will vary, but their performance can be measured if a baseline scenario is used.

Experiments

All three simulators were used for this test, but only SNT will provide a release for this publication. Confidentiality agreements make impossible the publication of the other results. Nevertheless, our interest is to provide a testing model, not a review of ongoing CES development.

Our proposed baseline consists of two groups of vehicles in proximity and moving separately but supporting each other so that the communication failures can be observed as vehicles move out of any communications range or as transmission is obstructed by terrain. Each group consists of a subnet of five vehicles that share a network with another group of five vehicles that form their own subnet.

As specified by FCS standards, each cell that moves through the terrain and experiences loss of communication due to terrain obstacles, distance or destruction by the enemy should regroup and reestablish new connections with unobstructed or existing cells. Therefore, it is important to establish a communications baseline between the studied cells to check that cell behavior is correct. Initial tests are used as the communications measurement best case scenario. Hence, the initialization of the network can be monitored and checked for typical FCS operation. Once a baseline has been established, the mobility of the vehicles can be programmed to follow the streets near the airport using GPS waypoints. Observations can then be made to determine JTRS radio limitations when compared to the model.

SNT CES provides an FCS infrastructure to enable the user to experiment with the location and movement of FCS vehicles considering different protocols limited by the capacity of the JTRS radios. Other CES studied were not as flexible, but internal file modification permitted relocation and GPS waypoint following.

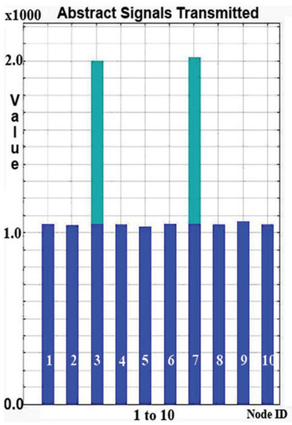
We configured SNT with the proposed scenario, where both subnets (cells) were separated approximately 1.5 Km, and without using a terrain database. Initially simulated experimental results show that the network has

no connectivity for about twenty seconds, which is the approximate time that the network needs to initialize its mobile net and subnets.

Examination of the physical layer presents a solid transmission of signals throughout the 200 minutes of simulation, proof of the nearby location of the other cells and the lack of interference from the terrain.

On the graphs shown the x-axis corresponds to the number of nodes in the simulation where two cells of 5 nodes each are tested. Cell 0 includes nodes 1, 2, 3, 4 and 5. Similarly, cell 1 contains nodes 6, 7, 8, 9 and 10. Pair Nodes 1 and 5, and 7 and 10 are connected directly through Ethernet. Each cell moves through the designated area increasingly away from each other for 200 minutes. The colors of the bars represent each cell group plotted, blue for cell 0 and green for cell 1.

In figures 5 and 6, most signals get passed to the MAC layer with higher concentrations on cells 3 and 7 due to proximity to each other.



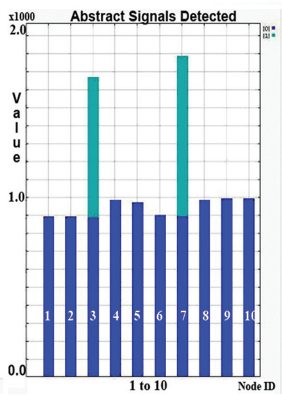


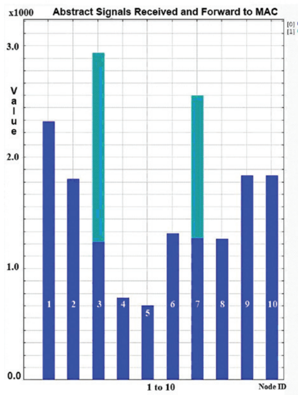
Figure 5: Abstract Signals Transmitted

Figure 6: Abstract Signals Detected

Observe that not all the signals transmitted by a source at the physical layer were received at their destinations due to inherent losses during transmission.

On the following OSI layer, MAC [13][14] the packets received from the network layer have no Unicast packets component on the network, which agrees with High Level Architecture (HLA) using only UDP and Broadcasting. A description of HLA will exceed the contents and scope of this paper, but in general terms HLA only broadcasts to members of its network using UDP. For more details on HLA, see [15]. Signals received and forwarded to the MAC layer are less than the abstract signal transmitted initially as expected. In figure 7, notice how nodes 4 and 5 experience some communication loss for this test due to HLA nature.

Not all packets transmitted are used by HLA, only UDP. In figure 8, most broadcast packets are received from the network layer due to HLA's broadcast-only nature.



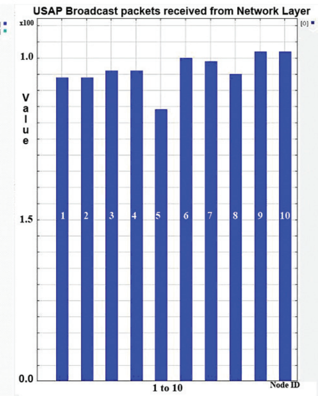


Figure 7: Abstract Signals Received and Forwarded to MAC

Figure 8: USAP Broadcast Packets Received from Network Layer

On the transport layer no UDP and TCP packets are observed [13][14], only UDP packets as the HLA/DIS protocol specifies. As seen in figure 9 the activity of UDP packets is almost constant for each node; there is no TCP activity as expected in HLA.

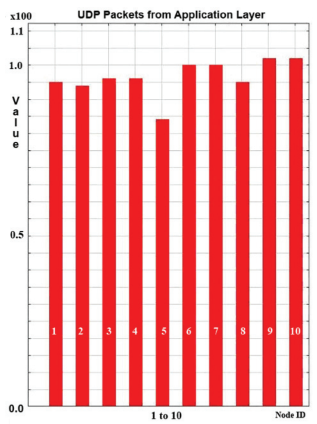


Figure 9: UDP Packets from Application Layer

Observations can be made after the baseline is executed in each CSE simulation. The user should look for discrepancies regarding the communication channel characteristics and its interaction with its surroundings and terrain. Note that different signals at different frequencies travel different paths [16]. A JTRS signal may overcome obstacles while operating at lower frequencies otherwise impossible to overcome at Ultra High frequencies. Iteratively, the fidelity of each CES can then be verified as well as its embedded training capabilities.

Figure 10 depicts our test simulation performed on the Qualnet SNT simulator at the Atyarau location with the cells in the strategic initial GPS locations. In this simulation the connectivity between all the cells was evaluated to determine that the behavior of random communication between the cells is acceptable within the expectations of the data transport and the movement of the cells. The graphs in figures 6 to 9 show that an initial transmission or random signal loses data as it traverses the different layers of the OSI model due to HLA operating with a subset of the initial data concentrated on UDP packets. Nodes 4 and 5 suffer from below average communication since they are the cells that moved the furthest from each other.

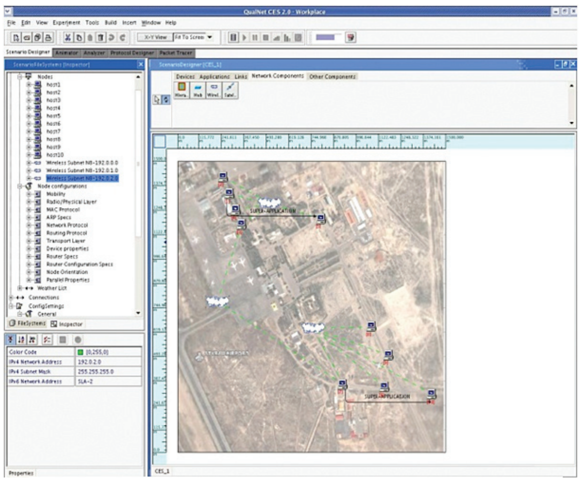


Figure 10: FCS Test Scenario in Qualnet

Nevertheless, setting up a simple scenario for testing FCS mobility as suggested is rapid if the models behave as expected. Given that the CES in question provides the flexibility to set initial conditions such as terrain location and cell configuration, a small scenario can be built to verify the CES accuracy before committing to a larger exercise.

For this particular CES test, the initial GPS location for each cell was defined. Using random paths is not recommended since it leads to the inability to establish a baseline for comparison between different CES tools.

After setting the paths for each cell, considerations about the weather can be added. Setting up the correct path is important since the distances between the cells and interactions with other cells affects the communication. Cells traversing between many obstructions can lose their capability to communicate. Distances over 5 Km for handheld radios and 15 Km for Small Form Fit (SFF) radios are common with LOS free of interruptions. With radio bandwidth limited to 2 Mbps, real-time video is impossible without interruption. Therefore selecting a difficult path and initial long distances between the cell-vehicles is not recommended, but can determine the extent of the communications as the cells try to regroup their subnet as part of a different region. Likewise, embedded training in addition to the subnet traffic may decrease the ability to communicate correctly by limiting the available bandwidth. Some simulators provide an opportunity to embed additional traffic in parallel such as the SNT simulator presented using distributed CES which interacts with the Message Transceiver System (MTS). MTS is a message system that allows the CES to interact with other parts of the System of Systems Virtual Framework (SVF).

Figure 11 depicts our suggested baseline for Embedded Training FCS communications testing. The scenario consists of two subnets. This can be increased to 4 subnets if computation power is not a constraint. Each subnet consists of five mobile FCS communication cells with a starting distance between them no larger than 10 Km which is within the limit of JTRS communication. All cells within each subnet will initiate travel together and there should not be further than 0.5 kilometers between cells to accommodate minimum transmission requirements for all radios. These form a region after the initial 20 sec network setup time.

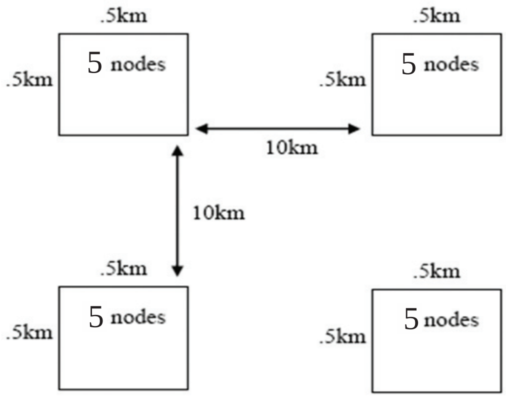


Figure 11: Baseline Scenario

Within the next 10 minutes of travel each cell will disperse from the others in a star configuration at a speed (in KPH) no faster than ½ the total distance in Kilometers of the exercise to allow 120 minutes of simulation time. This scenario is used to place demands on the FCS routing to regroup cells into other regions that connect with cells in proximity. Meanwhile the opposite subnets will be moving towards the airport trying to establish communication if it is not yet already established. After 20 minutes of simulation time the cells will start regrouping, but following

the paths or roads assigned by preprogrammed waypoints at a constant speed (in KPH) no faster than ½ the total distance in Kilometers. During this period, the signal and communications should strengthen, and separate regions for a subnet become a single region again. From this point onward as the two (or four subnets) get in proximity, new regions will be formed.

The bandwidth will shrink as all packets on the network intensify their collision rate with increasing obstacles and interference effects [13][14]. The overall communications of the small exercise presents a normal behavior for LOS communication between the cells. The interaction with terrain database should show a different behavior that we are unable to test here due to limitations on terrain data access.

Similar evaluations can be done to verify the accuracy of any communications simulator rapidly. The setup time is less than 30 minutes and the execution time less than 30 minutes.

Conclusion

The estimation of the capabilities of a particular CES is no easy task. The evaluation of its usability and fidelity can be done rapidly with small scenarios that evaluate known network properties of the models used by the simulator in a black box test. By using a priori analysis of the models compared with the original design characteristics, it is possible to explore the limits of JTRS radios, for example, and interconnected networks and verify the simulator's fidelity.

The use of JTRS radios as the main hubs for WIN-T networks on a moving battalion [17] communication is a limiting factor in the success of embedded training in situations where video information is needed for enemy awareness especially in broadcast HLA format. CES experiments can verify and suggest the best configuration for ideal bandwidth optimization.

Testing JTRS capabilities and limitations can be done with existing CES by exploring their capabilities on a small controllable network where the interactions with terrain and the distances needed to communicate are controlled. By setting a small group of vehicles as cells as suggested, bandwidth studies are possible. Moreover, similar experiments can verify the fidelity of the radiation pattern of each radio as it travels through terrain and check its capabilities at different frequencies. Please note that none of the CES evaluated had the capability to change model behavior as their transmission frequency was changed. Remember that waves travel differently and diminish their ability to travel through solids as their frequency increases.

Not all CES will produce the same output results. By performing the suggested Black Box testing, a heuristic observation of the operation can be sufficient to determine the capability of the product for this purpose. However, it is more daunting to quantify the results when the details of these designs are classified or difficult to locate. Therefore a behavioral analysis is more convenient and a preamble to detailed results.

Access to military terrain data can be difficult, but interaction between terrain and communications can be done with available open source data. Most of the CES evaluated had the ability to read DTED and USGS data as well as other formats.

Future Work

Ultimately we will like to have access to DTED or USGS DEM Caspian Sea data for the airport presented in this paper to test the nuances of the CES simulators. We will like to run the same scenario and observe variations in data as the vehicles traverse through obstacles such as walls and mountains. Moreover, some of these products advertise the ability to interact with weather, a capability we would like to compare with terrain and non-terrain interaction and postulate a better model to verify the fidelity of each particular CES module.

As new technology emerges and the SOSCOE implementation is defined, other CES products will emerge. Users will need a baseline to test the initial fidelity of the tool and compare bandwidth results with other tests to ensure fidelity. Our proposed baseline can be used to assist users in obtaining a certain degree of confidence about the fidelity of the CES tool built, evaluated, or purchased

Other commercial simulators such as OPNET can be used with our proposed scenario to observe their capabilities and determine their suitability for FCS terrain and weather effects simulation.

Network Communication Effects Simulator Evaluation Scenarios for Joint Tactical Radio System (JTRS) and Warfighter Information Network-Tactical (WIN-T)

Acronyms

C4I	Command, Control, Communications, Computers, Intelligence
C4ISR	Command, Control, Communications, Computers, Intelligence and Reconnaissance.
CADC	Central Air Data Computer
CC	Communications and Computers
CES	Communication Effects Server
COTS	Commercial Off The Shelf
CSMA	Carrier Sense Multiple Access.
DEM	Digital Elevation Model
DTED	Digital Terrain Elevation Data
ET	Embedded Training
FCS	Future Combat Systems
FoS	Family of Systems
GPS	Global Positioning System
HLA	High Level Architecture
HSLS	Hazy-Sighted Link State Routing Protocol
IEEE	Institute of Electrical and Electronical Engineers
JIM	Joint Interagency Multinational
JTRS	Joint Tactical Radio Systems
LAN	Local Access Network
LOS	Line of Sight
MAC	Medium Access Control
MALSR	Multi-level Abstracted Link State Routing
MANET	Mobile Ad Hoc Network
MDL	Mobile Data Link
MI	FCS proprietary Mobile Internet
MPR	Multi-Point Relay
MTS	Message Transmitter System
OF	Objective Force
OSI	Open Systems Interconnection Basic Reference Model
RAP	Region Access Point
ROSPF	Radio Open Shortest Path First
SFF	Small Form Fit
SNT	Scalable Network Technologies
SOSCOE	Systems-of-Systems Common Operating Environment
SRW	Soldier Radio Waveform
SVF	Systems of Systems Virtual Framework
TDMA	Time Division Multiple Access
UA	Unit of Action
UAV	Unmanned Air Vehicle
UE	Unit of Employment
USAP	United Slot Assignment Protocol
USGS	United States Geological Survey
WIN-T	Warfighter Information Network – Tactical
WNW	Wideband Network Waveform

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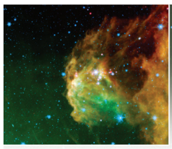
Biographies

Carlos Leon-Barth is a Research Assistant and Ph.D. student in the Department of Electrical and Computer Engineering at the University of Central Florida. He earned a BS (1993) in Electrical Engineering from University of Florida, MS (1996) in Computer Engineering from the University of Central Florida. He is a former Engineer for IBM Global Services from 1996-2002. His research interests are performance analysis of Computer Networks, Communication Systems and Simulation.

Ronald F. DeMara is a Professor in the Department of Electrical and Computer Engineering at the University of Central Florida. He earned a BS (1987) in Electrical Engineering from Lehigh University, MS (1989) in Electrical Engineering from the University of Maryland, and Ph.D. (1992) in Computer Engineering from the University of Southern California. Prior to joining UCF, he was an Associate Engineer at IBM Corporation in Manassas, Virginia. His research interests include design and performance analysis of Computer Architecture and Distributed Systems. He has published over 100 articles in these areas. He is a registered Professional Engineer in California, senior member of IEEE, a member of ACM, and ASEE.



Modeling Situational Awareness Using Scenario Objects and Events for Constructive Experimentation

Written by: *Philip Colon, John Tran, Ke-Thia Yao, Michael Anhalt, Jacqueline Curiel*

ABSTRACT: *Highly advanced sensor technologies give our military commanders a significant command and control (C2) advantage over our enemies during conflicts, particularly with respect to situation awareness (SA). The use of advanced sensor technology models in synthetic battlespace gives war fighters parallel advantages. Two accepted simulation methodologies for analyzing the impact of sensor technologies are through Human-in-the-Loop (HITL) experiments, such as Joint Urban Operations (JUO), which utilize sensor capabilities to assist human participants during the experiments, and Monte Carlo constructive (MCC) simulations, which can be used to model human performance. In HITL experiments using Joint Semi-Automated Forces (JSAF), participants describe their SA using Situation Awareness Objects (SAOs) which then can be reconstructed using Endsley's (1995) three levels of SA (perception, comprehension, and prediction). MCC experiments, which are dominated by algorithmically determined behaviors, can be used to model SA. Sensor measurements currently can be fused to perceive individual entities, but do not have the capability to recognize groupings of entities, resulting only in partial perceptual SA. Furthermore, current sensor data fusion models do not produce the second and third levels of SA, comprehension and prediction.*

This paper will report research efforts to utilize both methodologies to expand the use of SAOs beyond player declarations to the automatic generation of SAOs. We develop a method to organize events drawn from scenarios taken from HITL experiments using SAOs in order to develop situation awareness algorithms for the MCC runs. These model-generated synthetic SAOs (SSAOs) can be compared to SAOs generated by human players to identify the accuracy of the models as well as be used to identify strengths and weaknesses in player performance.

Introduction

This paper focuses on building a foundation for a research effort on modeling situation awareness (SA) in synthetic theater of war (STOW). We present a relevant research problem, and a description of how it can be modeled. We focus on SA because it has widespread relevancy throughout the military community and at all levels of the command hierarchy. We are also interested in SA because, as a complex mental state that is reflects numerous cognitive processes, it is a particularly challenging modeling problem. Being able to successfully model SA will have at least a two-pronged benefit, in our view. First, it would validate our assumptions of the results of Human-in-the Loop (HITL) exercises in which human participants are a part of the simulation. Second, our approach is applicable to SA-related issues, including command and control (C2) and training.

Motivation

There are two accepted experimental methods for evaluating sensors technology: HITL experimentation and Monte Carlo Constructive (MCC) experiments, which are statistic-based constructive experimentation of sensor models. For HITL experiments, SA output is a function of human behavior. The use of constructive runs, up to this point, in sensor modeling and simulation experiments has been conducted independently of consideration for human interactions and attempts to model situation awareness have been limited to its more perceptual aspects. HITL experiments yield a wealth of data and if the MCC methodology can be used to develop tools to give analysts a synthesized encapsulation of events akin to the information provided by the HITL players, they can make better use of resources (time and personnel) to make better decisions.

Our approach is directly tied to ongoing HITL experimentation by the Forces and Modeling Simulation (FMS) Group in the J9 Directorate at the US Joint Forces Command (JFCOM), the evolving sensor modeling technology by Toyon Research Corporation, and the research and support in synthetic battlespace by Alion Science and Technology.

General Overview

Our proposed SA analysis framework, in the context of STOW, specifically in Joint Semi-Automated Forces (JSAF) simulation software, can be summarized as follows. The experiment consists of a game that is played among two or more potentially adversarial forces (i.e., blue, red, and green cells). The objective of the red and blue cells is to tactically outmaneuver the adversary. These experiments operate on the assumption that complete and superior SA, relying on the aid of sensor technology, is the key to success. In these experiments, players demonstrate SA when they detect and accurately interpret sensor data.

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For our purposes, Figure 1 illustrates the flow of information through a system, from sensor data (input) to SA interpretations (output). Sensor data and other simulation information are fed into a cognitive "black box", resulting in SA. For Figure 1 the signature refers to an entity's identifying characteristics, SA level 2 includes the recognition of behavioral patterns and kinematics (motion) and SA level 3 includes the application of learned behaviors to predict intent.

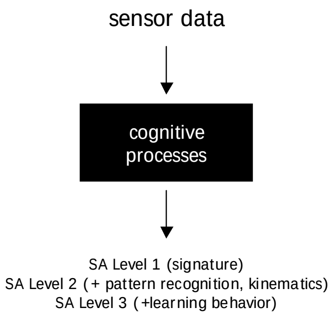

Figure 1. Information Flow from Sensor to SA output

In the case of the HITL experiments, the black box represents the human players' cognitive processes involved in updating their mental representation of the situation based on information from sensor data, prior knowledge, and their previous SA. The outputs of these processes are the SA products. In the case of constructive simulations, as there are no human interactions, the formulation of these processes is algorithmic.

Problem Description

The research problem considered here focuses on developing a situation template of emplacement to be used for future MCC experimentation. We first define situation awareness and its use in HITL experimentation. We then describe the sensor simulation platform and software and the possible way in which the algorithms are implemented. Finally, we will consider a case study of SA using data collected from human players.

Situation Awareness Defined

There tends to be widespread agreement as to when good and poor SA is observed, but the numerous definitions of SA illustrate the difficulty of precisely defining SA. Many of these definitions are not useful for our purposes because they do not provide a sufficient framework for specifying the variables that are likely to influence SA. Perhaps the most widely accepted view is that of Endsley's (1998) multi-level approach. This view has come to be adopted by the military community for research, training, operations, and other purposes, and provides a framework suitable for our purposes.

According to Endsley, SA can be described as consisting of perception, comprehension, and projection (see Figure 2). These levels represent the products of separate cognitive processes, yet the products from one level are influenced by those of other levels.

The perceptual level involves the detection, recognition, and identification of elements that define a specific situation. Perceptual SA relies on available sensory information, (e.g., from sensors in the case of a player in a HITL experiment) and the player's prior knowledge (e.g., object patterns/schemas activated in memory) to identify individual situation elements and object groups and their characteristics. Level 1A perception corresponds to the identification of individual entities (e.g., a tank); Level 1B perception corresponds to the identification of a grouping of entities (e.g., a mechanized brigade). The sensor fusion processes that are involved in associating tracks from different sensor sources or in grouping entities reflect perception.

The comprehension level (Level 2) reflects an understanding of the current situation, mapping perception to function. In battlespace, comprehension involves identifying the enemy's current activities. Finally, the projection level (Level 3) reflects predictions about the trajectory of the situation based on the products of the lower levels of SA and prior knowledge. In battlespace, projection corresponds to intent: what will the enemy do? Our contribution to this paper focuses on how MCC experimentation can accomplish the mapping of perception to function thus involving both Level 1 and 2 SA.

HITL Experiments

The US Joint Forces Command (USJFCOM) conducts Joint Urban Operation (JUO) series of exercises in synthetic domains using human-directed computer simulation tools, such as Joint Semi-Automated Forces (JSAF), to

explore and analyze current and future Joint war-fighting capabilities. HITL actions and interactions are important components of these experiments, where humans control the activity and influence the outcome of the exercises. Humans control simulated Intelligence, Surveillance, and Reconnaissance (ISR) sensors and use Situation Awareness Objects (SAOs) to declare and share their perceptions regarding model generated detections and track objects.

Situation Awareness Objects (SAOs) in HITL

In order to evaluate the effectiveness of game-play in the JUO exercises, we employ a novel tool called SAO, which is a method of recording information about red force entities that has only been used this series of experiments (Anhalt, 2006). The SAO is a compact package of information that players create and place on a shared terrain map that contains their thoughts, assumptions, and understanding about the enemy. Figure 3 is an example input screen in JSAF that allows puckers to annotate their SA state (create an SAO) during game play. SAOs are created by having players input information about the state of the entities.

Collect Data from JUO/HITL Experiments

The data to be used for the model comes from JUO/HITL experiments, including electronic data that are captured and archived during each trial (e.g., ground-truth unit information of all enemy, friendly and neutral entities, enemy unit track locations as perceived by the sensors and players) and Situation Awareness Object (SAO) information. Situational Awareness Objects are command and control tools designed for players to assess sensor results and share their findings. SAOs are key to evaluating the player's understanding of the battlespace and include player comments.

Sensor Modeling: Urban Resolve 2015

The vast developments in the fields of computer engineering and computer science have allowed for the efficient modeling of increasingly complex and computationally expensive sensor systems. As technical advances are made, additional resources become available for many problems that may have strained computing resources in the past, if they were possible at all. One highly effective use of modeling and simulation is the rapid prototyping of future systems. This use has allowed researchers to implement and discover new ideas based on state-of-the-art technological advances, as well as adapting to changing environments and current day military defense and defeat needs.

For the last several years, JFCOM HITL experiments have focused on asymmetric threats and have explored advanced future sensor technologies as solutions to defeat these threats. In so doing, a paradigm shift has occurred whereby HITL player involvement was expanded to involve interpreting formerly incidental pieces of information, or otherwise insignificant simulation artifacts, and recognizing that those events play a formal part of understanding the enemy.

For example, in Millennium Challenge 02 and Urban Resolve Phase 1 in 2004, only the graphical representation of an entity was relevant; events such as digging and

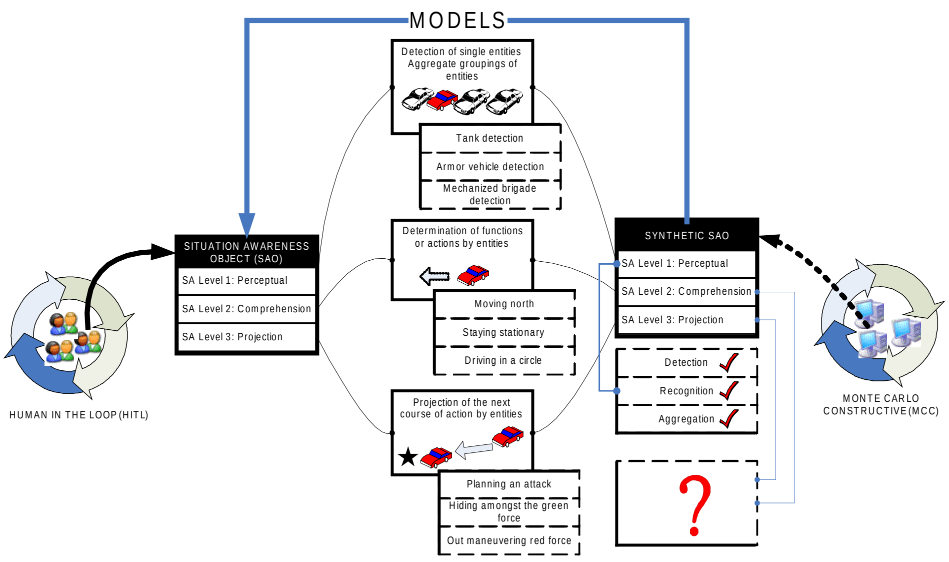

Figure 2. Endsley's (1998) Multi-Level Approach to Situation Awareness

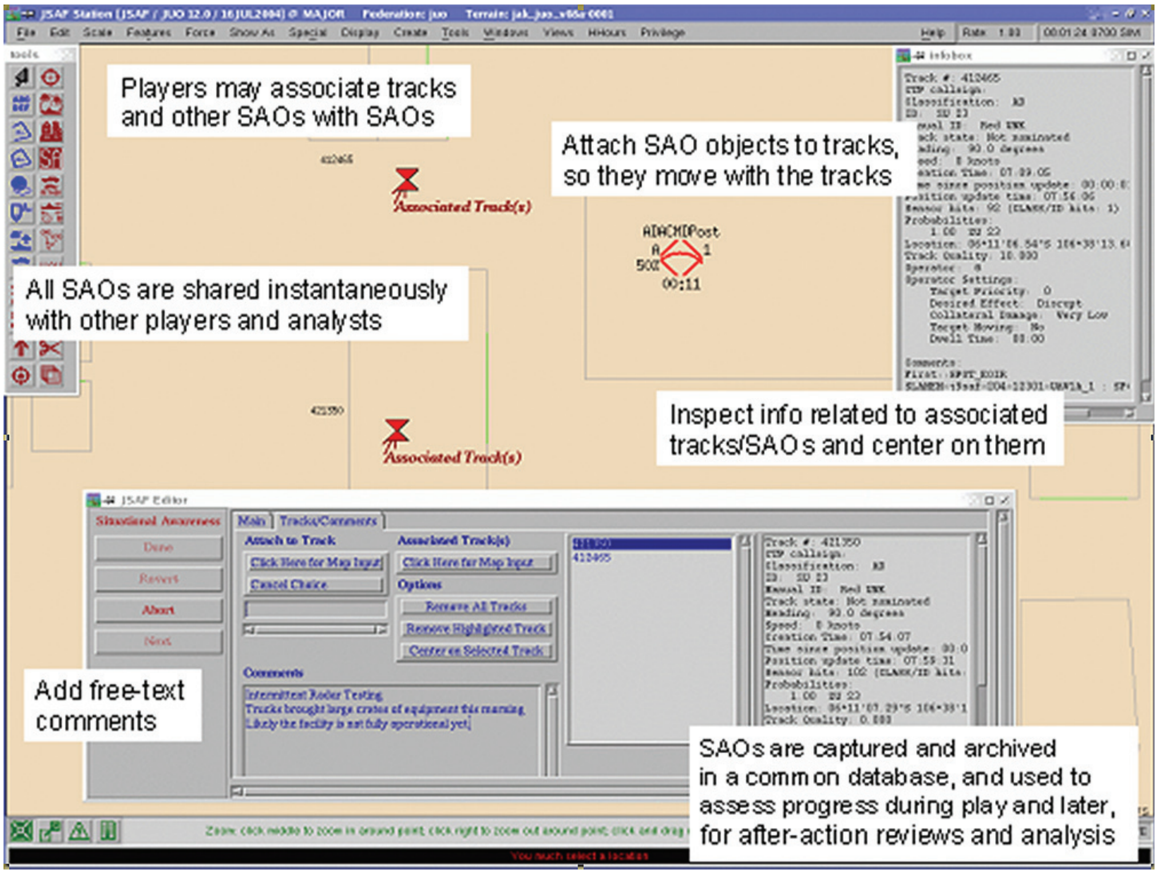

Figure 3. An Example Input Screen in JSAF

loitering within a group were not significant or were simply not a capability that existed in the simulation. As implemented in the J9 Directorate's Urban Resolve 2015 (UR2015) experiment of 2006, interpreting these events was critical to understanding SA. HITL players were trained to expand the scope of SAO involvement as the primary means of capturing the new pieces of information. SAOs became the central component to threat identification and interdiction within the experiment.

Description of SSAO

This paradigm shift also had the affect of creating a larger separation between HITL and MCC results by enhancing the overall impact human interpretation of events had on the experiment outcome. With MCC based experimentation focused on Level 1 SA, our contribution in this paper will make an evaluation of official UR2015 trial run SAO data, and use that data as a means to facilitate generating higher-level SA in MCC runs.

Our ultimate intent is to successfully bring together the most beneficial elements of HITL experiments, namely the unique perception abilities brought by players, and the scalability and efficiency of an MCC experiment. To effectively model patterns of player performance, the concept was developed to automatically generate Synthetic Situation Awareness Objects (SSAOs) for MCC experiments. The SSAO is a generic construct that will facilitate capturing all three levels of SA in an MCC experiment in a manner parallel to the SAO in a HITL experiment. These objects encapsulate and automate the (1) detection of entities and the grouping of these detections, (2) identification of the activities of these entities, and (3) derivation of heuristic models for intent of the opposing force as represented by the entities. Figure 4 below demonstrates the three levels of SA that would be required to be encapsulated by an SAO/SSAO during HITL and MCC Experimentation.

Figure 4. Three Levels of SA to be Captured by SAO/SSAO

SLAMEM: The MCC Simulation Testbed

JFCOM sponsored large scale HITL experimentation, including UR2015, has used the Simulation of the Location and Attack of Mobile Enemy Missiles (SLAMEM™) for simulating ISR capabilities in the JSAF federation. SLAMEM is an entity level, event based simulation that was developed for analyzing the performance of coordinated command, control, communications, intelligence, surveillance, reconnaissance (C4ISR) and targeting systems against time-critical mobile targets. SLAMEM has also been utilized in performing numerous MCC experiments on behalf of JFCOM. SLAMEM's role in supporting surveillance and targeting activities includes analyzing advanced C4ISR architectures. SLAMEM analyses have several objectives, including: (1) quantifying the potential improvements in effectiveness provided by the advanced architecture; (2) deriving the performance required from the technologies to achieve specific mission-level goals; and (3) developing new CONOPS for using the technologies most effectively. As the threat environment evolves, it has become more important to consider human perception factors when making the above 3 assessments.

MCC Experiments

Monte Carlo-based simulations are closed form constructive processes that have no human interaction during runtime. The results of MCC experiments are dependent on the scenario metrics and random statistical variations from run to run, and are initiated with a unique random seed. These statistical variations can hinder meaningful results from MCC experiments if care is not taken to make sure a sufficient number of trial runs are completed (that is, random variations alone should not dictate the outcome of any run). This, however, is generally not a road block even when the number of trial runs is large. This is due to the fact that MCC runs do not require constant monitoring and lend themselves rather well to batch processing for this reason.

The lack of the human component allows for greater scalability in the number of variables experiments can explore.

A limitation of MCC runs is that only the most basic levels of perception are considered for evaluation. Specifically, for SA Level 1, the acquisition of entities in the environment, and ability to maintain persistent surveillance has been the main focus. This is primarily due to the fact that there are no human interactions, and thus no human providing insight into the problem. But for MCC experiments to maintain their relevance, they must adapt to the growing trends of enhanced perception requirements.

Modeling SA in MCC with SSAO

The HITL experiments place an emphasis on the importance of human interactions and the output of the experimentation is a function of human behavior, and is measured using the metrics of Situation Awareness (Curiel, Tran, Anhalt & Yao., 2005). On the other hand, up to this point, sensors modeling and simulation experiments in the context of constructive simulations, by definition, have been conducted independently of consideration for human interactions. Notably missing is the lack of focus on a situation model.

Currently, MCC experimentation is developed with underlying fusion algorithms that can provide a means of synthesizing rudimentary components of SA. These components make up the first level of SA which answers the so-called "what" question. In the case of the models that have been experimented, the "what" question answers the specific questions of what is being observed or detected by the sensor models. They also provide, with the use of various heuristic algorithms, the ability to aggregate the detections into composite units, also referred to as Level 1B SA (Tran, Yao & Curiel, 2004). For example, the detection of a group of "metal" vehicles by the sensors can be funneled through the Fusion Center and the output is classified as a mechanized brigade (Castleberg, Colon & Berger, 2006). The ability to extend the constructive experiment model to cover the second and third level of SA in MCC experiments would provide a more complete experimental framework that validates the effectiveness of sensor models – and doing so from a statistically relevant analysis standpoint.

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Automated Level 1 SA in UR2015

The UR2015 HITL experiment explored a trade space containing a wide array of sensor technologies. Each sensor, depending on its underlying phenomenology as well as its quality, aided situation awareness to varying degrees. This variability was characterized by confusion matrices. Confusion matrices were defined to be unique for each sensor, and also to provide a perceived view of the entities within the environment based on three dimensions (quality, camouflage, and azimuth angle). Confusion matrices represent the exploitation processes, whether automated or human-aided, which transform sensor data into detection and classification outcomes. The probability of detection, correct classification and identification of entities in the environment was determined by the following equation, commonly referred to as Johnson's criteria (Johnson, 1958; O'Connor, 2003):

$$P \cong \frac{\left(N/N_{50}\right)\left(a + bN/N_{50}\right)}{1 + \left(N/N_{50}\right)\left(a + bN/N_{50}\right)}$$

where

N = the number of resolvable cycles (equivalent line pairs) on target

N_{50} = the number of line pairs on target required for $P=0.5$

a = 2.7

b = 0.7

The outcomes of using Johnson's criteria per entity were used to populate the values of the confusion matrices. Figure 5 illustrates a generic example of a confusion matrix.

Perception

Ground Truth

		IDENTIFY						RECOGNIZE			
TRUTH	Pd	M35	SEDAN	T_TRAILER	T_72B	T_90	ZIL_131	CAR	TRUCK	TANK	UNKNOWN
M35	0.7	0		0.001	0.01	0.01	0.001		0.03	0.01	0.94
SEDAN	0.4		0.001					0.01			0.99
T_TRAILER	0.9	0		0.006			0.002		0.05		0.94
T_72B	0.7	0.03			0	0.003				0.027	0.94
T_90	0.7	0.03			0	0.003				0.027	0.94
ZIL_131	0.6	0		0.001			0.003		0.02		0.97
FALSE	1	0.02	0.022	0.022	0.02	0.022	0.022	0.02	0.02	0.022	0.8

Figure 5. Example of the Format for a Confusion Matrix

SA is initiated through sensor tasking and is developed through outcomes of sensor-target interactions and subsequent confusion matrix draws. That is, if say 10 entities fall into a single beam of a sensor, each of those 10 entities would be perceived separately and generate 10 distinct sensor-target interactions.

An important development in the field of modeling and simulation has been the change in focus from a strictly entity based visual perception of the enemy, to a more context-based perception of who is likely to be an enemy (Ceranowicz, Torpey, & Hines, 2006). This change in methodology has had a vast impact on the M&S sensor development community, and indeed on the players who control the sensors and interpret their output. The determination of who is likely to be an enemy is no longer based on what the entity looks like, but by viewing types of evidence such as the behavior of the entity at any given time, the accessories carried by the entity, and any actions the entity happens to be engaged in. The challenge of modeling and simulation is to make sure that each piece of evidence is sufficiently well modeled so that a HITL player has a chance to recognize the evidence, and discriminate with enough confidence targets of interest amongst the larger general population.

The scope of UR2015 was defined to provide a solution of persistent surveillance unmanned aerial vehicles (UAVs) fitted with high resolution imagery and video capable of detecting on the highest zoom setting enough of the pieces of evidence to address the problem scope. UR2015, with all the advanced sensors available to the players, was still only automated to the players SA Level 1 perception. Using Johnson's Criteria and assigning each piece of evidence a mean critical dimension, Equation 1-1 can be used to generate the probability of detection, correct classification, and identification for accessories and rudimentary actions, such as kneeling or loitering. When time is considered (i.e., an analyst reviewing sensor data over time), we may achieve recognition of behavior by utilizing the zoom feature of the video. It has been determined that to correctly classify small pieces of evidence, an image with resolution of better than 1cm is required (Castleberg et al., 2006). The UR2015 sensor solution required multiple looks in order to build sufficient confidence in a particularly small piece of evidence. The information provided over multiple looks was updated using Bayes' rule, and only when the belief in the truth identity of the evidence was reached (for UR2015 this threshold value was typically set to 0.80) a track was generated, containing information about the host entity's location and velocity, as well as a list of recognized pieces of evidence. Players then were left with the assignment of determining if any given piece of evidence, or the evidence as a whole, constituted suspicious activity. These tracks, in addition to the steaming video, provided the players with the necessary information to recognize suspicious behavior and create SAOs to reflect their SA during game play.

Table 1 shows a listing of available SAO types, as well as their relative frequency or appearance during game play.

Table 1. UR2015 SAO Types and Frequencies

SAO Types	Frequency
TerrorAct Other	42
Terror Act Meeting	8.5
TerrorAct Surveillance	1
TerrorAct Suspicious	4
TerrorAct Loitering	34
TerrorAct Fleeing	2
TerrorAct Event	8.5

SAO Case Study

Of critical importance to today's military is the threat of the improvised explosive devise (IED). For our consideration, we used data from actual events from UR2015 constituting an IED emplacement. The dataset was mined for TerrorAct SAOs where the players concluded that an IED placement was in progress or imminent based on one of several pieces of evidence. We define an IED emplacement scenario to be composed of the following: ingress of a vehicle to a location along the side of a sparsely populated road, 2-man team emerges and loiters, 1 of the 2 proceeds to the center of the road and kneels with a shovel, an IED is left behind, individuals proceed to the car and mount for egress. The process in sum lasts for no more than 30 minutes. The scenario also contains persistent high resolution imagery surveillance with one Predator viewing the area. Figure 6, a screen capture taken from the actual simulation tool used by players during UR2015, illustrates the scenario graphically.

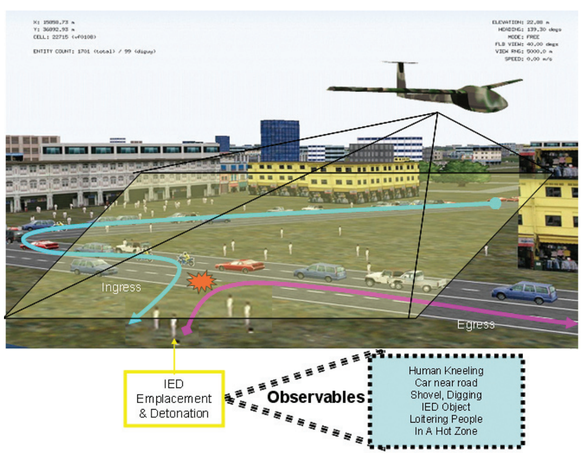

Figure 6. UR2015 IED Emplacement Scenario

SAO Case Study Results

The IED emplacement scenario was an important element of the UR2015 HITL trial runs, and players were trained on the indicators, or pieces of evidence, to look for to properly assess that situation. Figure 7 shows the pieces of evidence that composed each event and the relative frequency that each appeared as part of the players' decision-making process. For example, according to Figure 7, a player indicated that a "hot spot" was a relevant piece of evidence in 90% of SAO TerrorAct declarations.

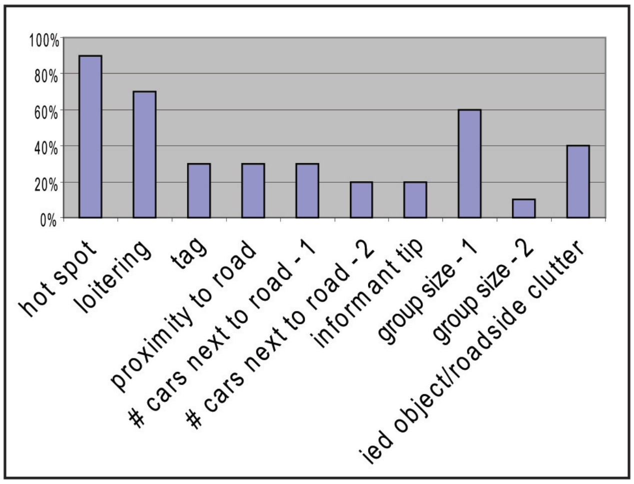

Figure 7. UR2015 Evidence and Frequency for Determining IED Emplacement TerrorAct SAOs

The UR2015 experiment scenarios were defined to bring together many aspects of behavior and actions. For players to identify a threat, they would have to identify several pieces of evidence and correlate them with each other. Figures 8 and 9 show the various pieces of evidence that players associated with IED emplacement events. Figure 8 shows that, on average, each IED emplacement SAO contained 4 distinct pieces of evidence.

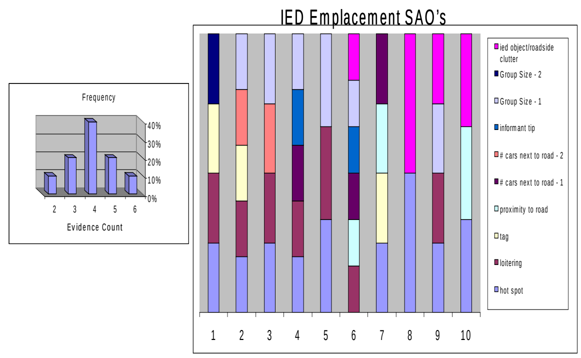

Figure 8. SAO Evidence Counts

Figure 9 shows that that the 10 IED emplacement SAOs from UR2015 were composed of 10 distinct pieces of evidence in different proportions. This data shows that, for example, most IED activity happened within a predefined "hot spot", in the presence of a single car

parked next to a road, with a lone individual in the near vicinity. The data showed that at no time wasa single piece of evidence sufficient to declare an IED Emplacement. In fact, on average, when a player designated an SAO, there were 4 pieces of evidence that contributed to it.

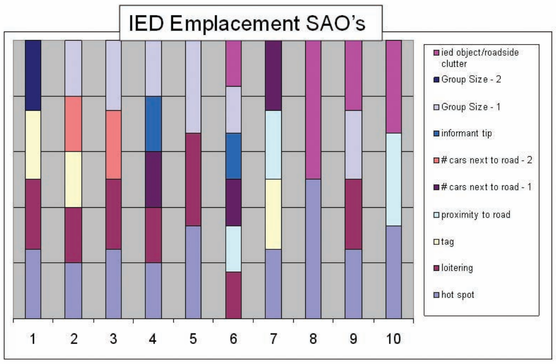

Figure 9. Evidence proportions for 10 IED emplacement SAOs

From SAO to SSAO

As mentioned previously, MCC runs are able to use algorithms focused on kinematics and features to determine rudimentary levels of SA. But these algorithms are not sophisticated enough to evaluate distinct measurements and group them together based on known, or learned, patterns to assess higher levels of SA. By using SAO data, we can train the algorithms to watch for specific pieces of evidence, each depending on the mission or CONOPS. Specifically for our test case of an IED emplacement, we may populate Table 2 from the SAO player data.

Table 2. Table of Evidence of IED Emplacement, with Definitions

Categories	Type	Specific	Definition
Actions	Loitering	Loitering	Individual standing or kneeling in roughly same location for several minutes
	Proximity To Road	Proximity To Road	Any action, location, or information located at roadside
Counts	Group Size	Group Size = 1	Observed individual is acting alone
		Group Size = 2	2 observed individuals close to one another
	Vehicle count parked at roadside	Vehicle Count = 1	Observed one vehicle parked along roadside
		Vehicle Count = 2	2 observed vehicles parked along roadside
Objects	Tag	Tag	A person or vehicle with any type of tag
	Object on Road	IED/Clutter object	An observed object laying on the road (either a roadside clutter or IED)
Information	Location	Hot Spot	Action or object observed in known area of interest
	Tip	Informant Tip	White cell injection that suspicious activity is taking place.

IED emplacements in the real world vary in every dimension, so we focus on the essential elements of an emplacement to keep the scenario tractable for analysis. A review of the SAO data suggests an a priori emplacement template for generating SSAOs in MCC runs, indicated by Figure 9.

Results and Discussion

The research reported here is still in early developmental stages. However, we feel that that the direction we are taking offers vast potential for improvement of human performance in SA. One such example is the interplay between sensor development and human performance whereby behavior drives the technological requirements that contribute to sensor development. For example, looking at the evidence a player relies on is informative about the sensor technologies that are valuable. Being able to determine the physical attributes of the entities, as seen through stealth view, that were important to players discovering suspicious activity would lead us to conclude a need for high resolution cameras capable of detecting such attributes. When factoring in the need to have these cameras mounted on a UAV, aerostat, or towers operating at low light levels and at night etc., then player outcomes help define technology requirements.

Other potential applications to our approach include the following:

- Further refining SAOs to allow for automation between sensor and player output.
- Training for SA, such as by identification of player biases.

Concluding Remarks

Human-In-The-Loop (HITL) experimentation provides researchers with firsthand data of how sensors and sensor systems are utilized by the players. Through observation during trial executions, researchers and analysts can watch the players while they make important time critical decisions on how to improve their situational awareness through the use of one or more sensors in theater. SAO objects are the key data element for understanding the players' choices at any given point in time. Analyses of these data can yield important information about how the sensors or sensor systems were employed, and what situations/scenarios were the most useful. Understanding this data better can illustrate operational needs more clearly, which can thus affect the design process of the sensors or systems. As for systems currently fielded, these data can provide insights on how to tune the sensors for better effectiveness during varying conditions.

Even with the benefits of human interactions and decision-making during sensor effectiveness studies, due to the fact that HITL experimentation requires a great deal of on-site personal support and financial resources, Monte Carlo constructive simulations are an attractive alternative. MCC runs require much less support than HITL experiments and are quite reliable at highlighting the capabilities of many sensors and sensor systems over a wide range of conditions. Currently, the lacking elements of Monte Carlo constructive simulation runs involve higher levels of situation awareness, such as the process of understanding incoming sensor data, associating tracks based on this data, and deducing enemy intent. By developing an algorithmic approximation to determining SAOs based on previous HITL data points, Monte Carlo constructive simulation runs can achieve a higher level of situational awareness that is not currently being obtained. Encapsulated within SAOs are keys to understanding the above mentioned process where a player takes sensor data and uses it to update the overall knowledge of the battle space. The outcome of the constructive runs can therefore expand upon the notion of sensor and sensor system capabilities to include new areas such as the usability of the sensors and sensor systems.

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Biographies

Philip Colon is an analyst with Toyon Research Corporation, supporting the USJFCOM J9 Experiment Engineering Department. He has supported numerous sensor systems analyses and also functions as Toyon's chief software engineer for distributed simulation experiments, including JUO Urban Resolve Phase 1. At Toyon, he focuses on technical analysis, modeling, and simulation of sensors and weapon systems operating in hostile environments. He received a B.S. with honors in Mathematics from the University of California at Santa Barbara.

John J. Tran is a researcher at the Information Sciences Institute, University of Southern California. He received both his BS and MS Degrees in Computer Science and Engineering from the University of Notre Dame, where he focused on Object-oriented software engineering, large-scale software system design and implementation, and high performance parallel and scientific computing. He has worked at the Stanford Linear Accelerator Center, Safetopia, and Intel. His current research centers on Linux cluster engineering, effective control of parallel programs, and communications fabrics for large-scale computation.

Ke-Thia Yao is a research scientist in the Distributed Scalable Systems Division of the University of Southern California Information Sciences Institute. Currently, he is working on the JESPP project, which has the goal of supporting very large-scale distributed military simulation involving millions of entities. Within the JESPP project he is developing a suite of monitoring/logging/analysis tools to help users better understand the computational and behavioral properties of large-scale simulations. He received his B.S. degree in EECS from UC Berkeley, and his M.S. and PhD degrees in Computer Science from Rutgers University.

Michael D. Anhalt is a retired Commander, USN, Surface Line with over 23 years of operational experience, including specialties in Amphibious Warfare, Surface, Undersea, and Strike Warfare, and tactical training. He has planned and directed system-engineering efforts in modeling & simulation and their integration with C2 systems. He supports planning and conducting war fighting exercises and experiments, prototype development, and new technologies for C2 Systems. He holds an M.S. degree in Educational Technology.

Jacqueline M. Curiel is a research psychologist at Alion Science and Technology and a co-founder of Behavioral Cognition and is a consultant to IdeaDaVinci. She received both her M.A. and PhD degrees in Psychology from the University of Notre Dame, where her research focused on spatial cognition and mental representations in narrative comprehension.

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